

Strength Studies on Metakaolin Modified Cement Mortar with Quarry Dust as Fine Aggregate

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Abstract— Scarcity of river sand is one of the major problems in the construction industry. Studies were conducted to find out the feasibility of using quarry dust to partially replace sand in concrete. . These studies revealed that, due to increased fineness, the combination require an increased water cement ratio which results in strength reduction or the use of a water reducing admixture. Use of super pozzolanic supplementary cementing materials such as silica fume, rice husk ash, metakaolin etc in concrete and mortar improves the strength even at a higher water binder ratio. Metakaolin, a manufactured material, calcined kaolinite is available at moderate cost. This paper presents the results of a study to use metakaolin in cement mortar as a partial replacement of cement where quarry dust was used as the fine aggregate. The effect of water binder ratio and metakaolin replacement level on the compressive strength of cement quarry dust mortar was investigated.

Index terms— fine aggregate, quarry dust, metakaolin, mortar, strength, density

I. INTRODUCTION

The development of infrastructures such as express highways, power projects, industrial structures etc., is essential in a country to meet the requirements of globalization. In the construction of buildings and other structures concrete plays a significant role and a large quantum of concrete is being utilized. River sand, which is one of the constituents used in the production of conventional concrete, has become highly expensive due to excessive cost of transportation from natural sources and also scarce. Also large-scale depletion of these sources creates environmental problems. As environmental, transportation and other constraints make the availability and use of river sand less attractive, a substitute or replacement product for concrete industry needs to be found. The use of alternate materials for sand in construction works need attention with respect to their availability and applicability. In this context studies were conducted to use quarry dust to partially replace sand in concrete. Quarry Rock Dust can be defined as residue, tailing or other non-valuable waste material after the extraction and processing of rocks to form fine particles less than 4.75mm. The consumption of cement content, workability, compressive strength and cost of concrete made with Quarry rock dust were studied by researchers. The studies [1] conducted on strength and durability properties of concrete containing quarry dust as fine aggregate revealed that the overall workability value of Quarry rock dust concrete is less,

compared to conventional concrete. Quarry rock dust concrete experiences better sulphate and acid resistance and its permeability is less, compared to that of conventional concrete. However, the water absorption of Quarry Rock Dust concrete is slightly higher than Conventional Concrete. The use of higher water cement ratio demands high cement content for a required strength. Studies reported in Ref. [2] revealed that the slump of crushed fine sand concrete mixes decreased with an increase in crushed fine sand content, probably due to its angular shape, when compared to river sand. At replacement levels of 75 and 100%, the compressive strength of crushed fine sand concrete decreased when compared with the control. Reference [3] report the effects of partial replacement of fine aggregate with crushed stone dust (particle size less than 75 microns), it was observed that slump value decreased as the percentage of dust content increased. Also for higher dust contents, the compressive strength, flexural strength, and impact resistance decreased gradually where as absorption increased. The use of quarry sand is generally limited due to the high cement paste volume needed to obtain an adequate workability of concrete. The amount of additional paste content depends on shape, texture, grading and dust content of the sand. The increase of water demand of concrete mixtures produced by the adverse effects of shape and texture of quarry sand can be mitigated using a high-range water-reducing admixture also. Both these remedies increase the cost of construction. Use of super-pozzolanic supplementary cementing materials in concrete and mortar improves the strength even at a higher water binder ratio. Silica fume, rice husk ash and metakaolin are considered as super-pozzolanic materials. The track record of these materials in the field of concrete construction is already established. High cost of silica fume is a barrier which limits its use in normal concrete construction. Rice husk ash, on the other hand develops increased heat of hydration causing shrinkage cracks. Metakaolin, a manufactured material, calcined kaolinite is available at moderate cost. The results from studies on metakaolin admixed concrete [4] showed that, as the metakaolin content increases, the slump value also increases. Optimum metakaolin replacement level in order to obtain maximum compressive strength is 20%. The three elementary factors which influence the contribution that metakaolin makes concrete strength are the immediate filler effect, the acceleration of OPC hydration (within the first 24 hours) and the pozzolanic effect of metakaolin with calcium hydroxide, between 7 and 14 days. Reference [5] report the studies of the effect of 15% replacement of cement in mortar with four metakaolin samples and compared to concrete containing

silica fume. Results showed that in mortars using metakaolin samples, the compressive strength development at early stages is at a higher rate than that of silica fume, but at later ages, metakaolin and silica fume specimens give similar strengths. The results from the studies conducted on rate of pozzolanic reaction of metakaolin in cement pastes [6] indicate that the rates of initial reactivity in metakaolin blended cement pastes were higher than in silica fume or fly ash blended cement pastes. Due to its high initial reactivity, metakaolin resulted in a higher rate of compressive strength development for cement pastes when compared with silica fume. The rate of pozzolanic reaction in metakaolin pastes became slower after 28 days of curing. After that, the pore size distribution of metakaolin pastes was slightly coarsened. This coarsening happened at a later age in a cement paste with a lower w/b ratio than in a paste with a higher w/b ratio. However, the pozzolanic reaction of metakaolin was still not completed at the age of 90 days with about half of the metakaolin unreacted. The degree of pozzolanic reaction and $\text{Ca}(\text{OH})_2$ consumption level of the silica fume pastes may reach or exceed those of metakaolin pastes at the ages of 28–90 days.

II. RESEARCH SIGNIFICANCE

Scarcity of river sand is one of the major concerns in the construction industry now-a-days. Quarry dust is an economical and easily available alternative to river sand. Earlier researches on replacement of river sand with quarry-dust revealed that there is a reduction in compressive strength of mortar or concrete. For getting the same strength as mortar with river sand; we have to add more cementitious materials. In the present investigation, Metakaolin, a manufactured supplementary cementitious material, is used to improve the mechanical characteristics of mortar made of quarry dust as fine aggregate. This report presents information regarding effect of water/binder (w/b) ratio on the compressive strength development of various metakaolin-modified mortar mixes made of quarry dust as fine aggregate. Effort was also put-in to determine the optimum metakaolin replacement level for all w/b ratios investigated and the optimum w/b ratio for all combinations.

III. MATERIALS AND METHODS

The materials used include Ordinary Portland Cement (43 Grade), metakaolin, quarry-dust, river sand and water. Cement, metakaolin, Quarry dust and River sand are tested for their physical characteristics as per the relevant standards. The results are presented in Table I and Table II.

TABLE I. PHYSICAL CHARACTERISTICS OF CEMENTING MATERIALS

Characteristics	Cement	Metakaolin
Specific Gravity	3.09	2.80
Standard Consistency, (%)	31.5	–
Initial Setting Time (Minutes)	140	–
Final Setting Time (Minutes)	480	–
Fineness (%)	4	–

TABLE II. PHYSICAL CHARACTERISTICS OF FINE AGGREGATE

Characteristics	River Sand	Quarry Dust
Fineness Modulus	2.85	3.39
Grading zone	Zone 2	Zone 2

Mortar cubes of size 50mm are used for the determination of compressive strength. Two control mixes are prepared – cement mortar 1:3 with river sand as fine aggregate (CR Series) and cement mortar 1:3 with quarry dust as fine aggregate (CQ Series). The CQ mixes are further modified by replacing a part of cement with metakaolin. The different cement-metakaolin combinations used here are 95% cement and 5% metakaolin (0.95+0.05), 90% cement and 10% metakaolin (0.90+0.10) and 85% cement and 15% metakaolin (0.85+0.15). Each of the above combinations is used for preparing mortar cubes with four different w/b ratios. The different w/b ratios adopted in this investigation are 0.35, 0.4, 0.45 and 0.50. The measured quantities of materials are mixed in a planetary type, variable speed mortar mixer. The prepared mortar is filled in 50mm cube moulds and compacted using a table vibrator. The mortar cube specimens are taken out of the mould after 24 hours of casting or at an early age, depending on the hardening potential of the mixture. The specimens are immersed in water for curing. Specimens are taken out of curing tank at designated ages (3, 7, 28, 56 and 90 days) and tested for their compressive strength. The weight of the specimen is measured prior to the test. The weight of the specimen is used to calculate the density of mortar

IV. RESULTS AND DISCUSSION

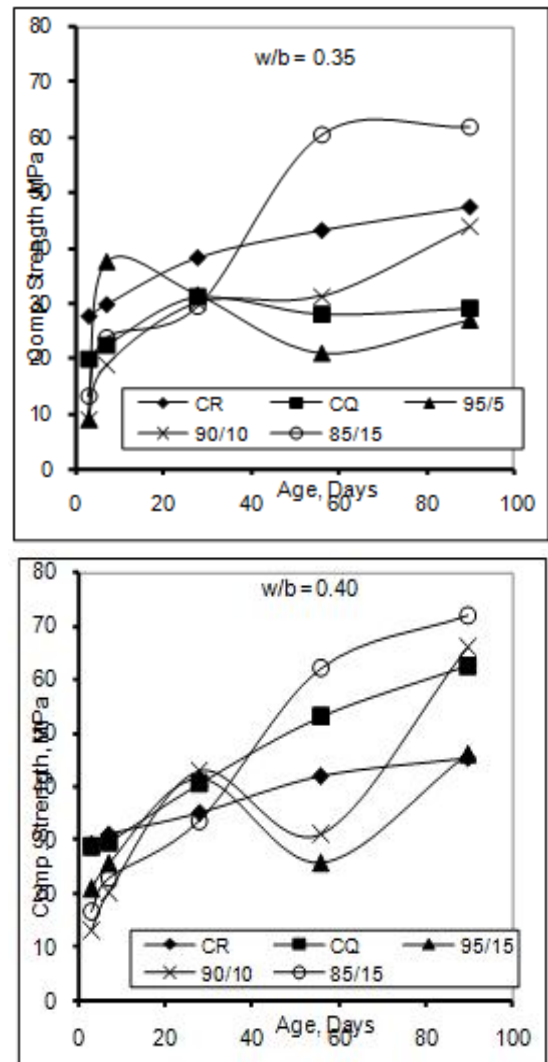
The development of compressive strength with age for all mortar mixes investigated is presented in Fig. 1. It is observed that the rate of early age strength development of metakaolin admixed mortar is higher for all water binder ratios. Maximum compressive strength value at 90 days is obtained for 15% replacement at all water binder ratios. Considerable

strength development takes place within 28-56 days for mixes with 15% metakaolin for all water binder ratios. However up to 0.4 water binder ratio, 5 and 10% replacement mixes shows a decreasing trend from 28-56 days. It may also be observed that a drop in compressive strength is observed for metakaolin admixed mortar specimens. This is probably due to the higher alumina content in the metakaolin which causes a conversion reaction of meta-stable calcium aluminate hydrate to more stable hydro garnet associated with a decrease in volume [7]. The drop in compressive strength decreases with increase in metakaolin content for a given water binder ratio. Also the decrease in compressive strength is almost disappeared in mixes made of higher water binder ratios. These behaviors of metakaolin admixed mortars is possibly due to the pozzolanic action of silica present in the metakaolin which improves the micro-structure. The effect of cement replacement with metakaolin on mortar with quarry sand is illustrated in Fig. 2. The plotted values are the percentage increase in compressive strength of metakaolin admixed mortar specimens with respect to the control mix with quarry dust as the fine aggregate. Negative values indicate lower strength of metakaolin admixed specimens than the control mix. The higher strength gain is reported for 85/15 mix with water binder ratio 0.35. The maximum strength loss is also reported for mix 95/5 prepared for the water binder ratio 0.35. The strength loss due to addition of metakaolin can be better controlled by adopting higher water binder ratio. Also the increase in metakaolin content improves the strength, irrespective of water binder ratio used. The effect of water binder ratio on the compressive strength of metakaolin admixed mortar cubes and control mixes at 28, 56 and 90 days is illustrated in Fig. 3. The control mix CR shows a general decrease in compressive strength at all ages as the water binder ratio increases. The control mix CQ shows an increase in compressive strength with increase in water binder ratio up to 0.40. But with further increase in water binder ratio, the compressive strength goes on reducing. As the age of concrete increases maximum strength is attained by 85/15 mix at all water cement ratios. Metakaolin admixed mixes shows an increase in compressive strength at lower water binder ratios and shows a decreasing trend with further increase in water binder ratio. The variation of density of mortar cubes for different mixes with variation in water binder ratio is illustrated in Fig. 4. For the two control mixes prepared, maximum density is observed at 0.40 water binder ratio. But in metakaolin admixed mortar cubes at all replacement levels, maximum density is observed at 0.45 water binder ratio. From the previous graphs, we have observed that with increase in metakaolin content, the compressive strength increases with age. Thus we can prepare mortar with higher water binder ratios to achieve higher compressive strength.

V. CONCLUSION

From the present investigation and limited observations reported, on the effect of partial replacement of cement with metakaolin in cement mortar cubes with quarry dust as fine aggregate with varying water/binder ratio, following conclusions can be drawn:

- The inclusion of metakaolin results in faster early age strength development of mortar.
- Mix with 15% metakaolin is superior in all water/binder ratios investigated.
- The drop in compressive strength due to conversion reaction, decreases with increase in metakaolin content for a given water binder ratio. Also this drop in compressive strength is almost disappeared in mixes made of higher water binder ratios.
- The increase in metakaolin content improves the compressive strength, irrespective of water binder ratio used.
- Metakaolin admixed mortar reaches their maximum density at 0.45 w/b ratio for mix containing 10% metakaolin.



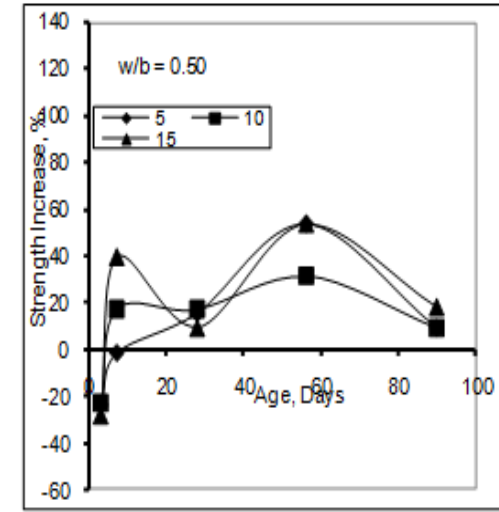
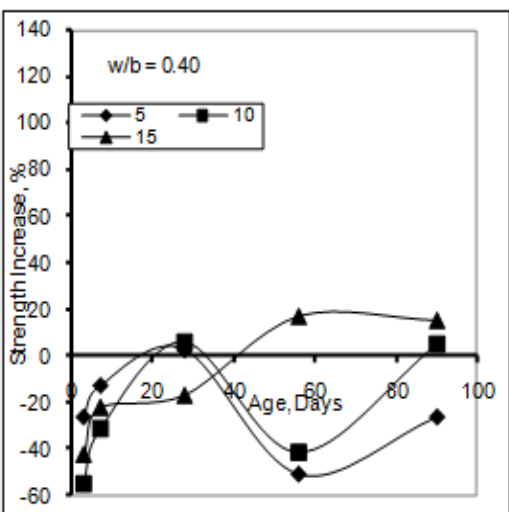
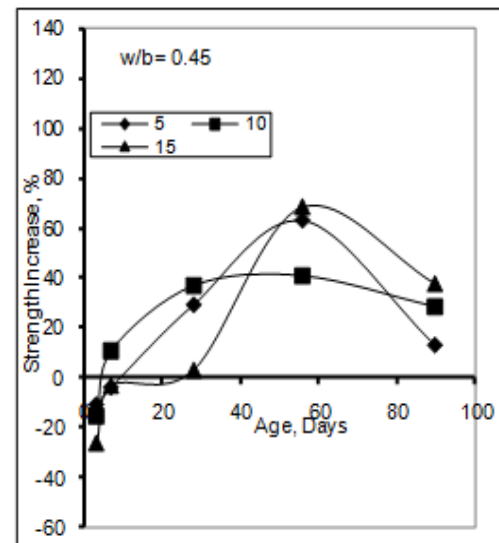
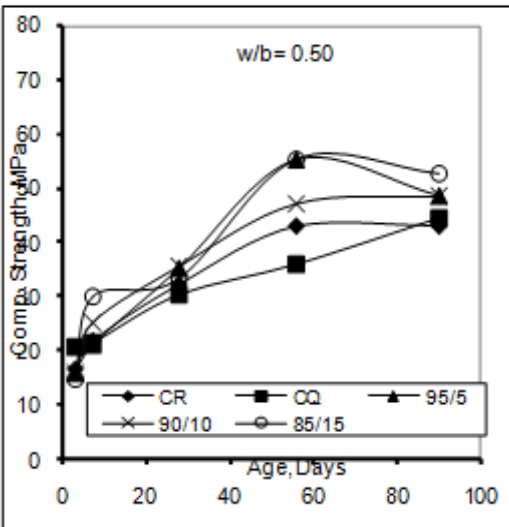
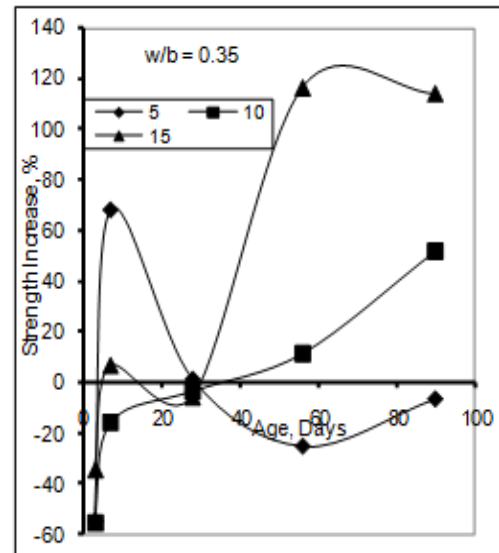
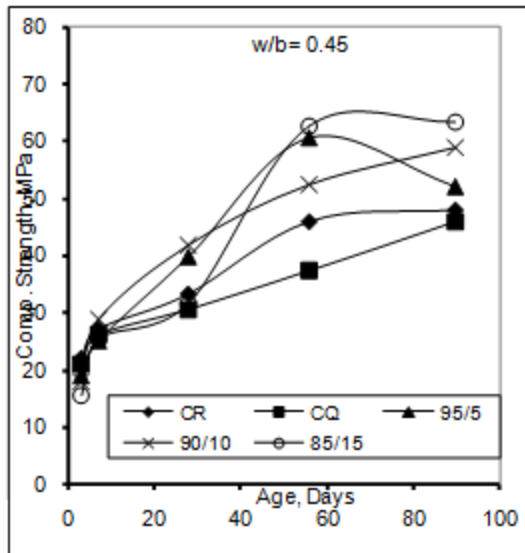


Figure 1. Variation of compressive strength with age

Figure 2. Effect of metakaolin content in cement – quarry dust mortar specimens.

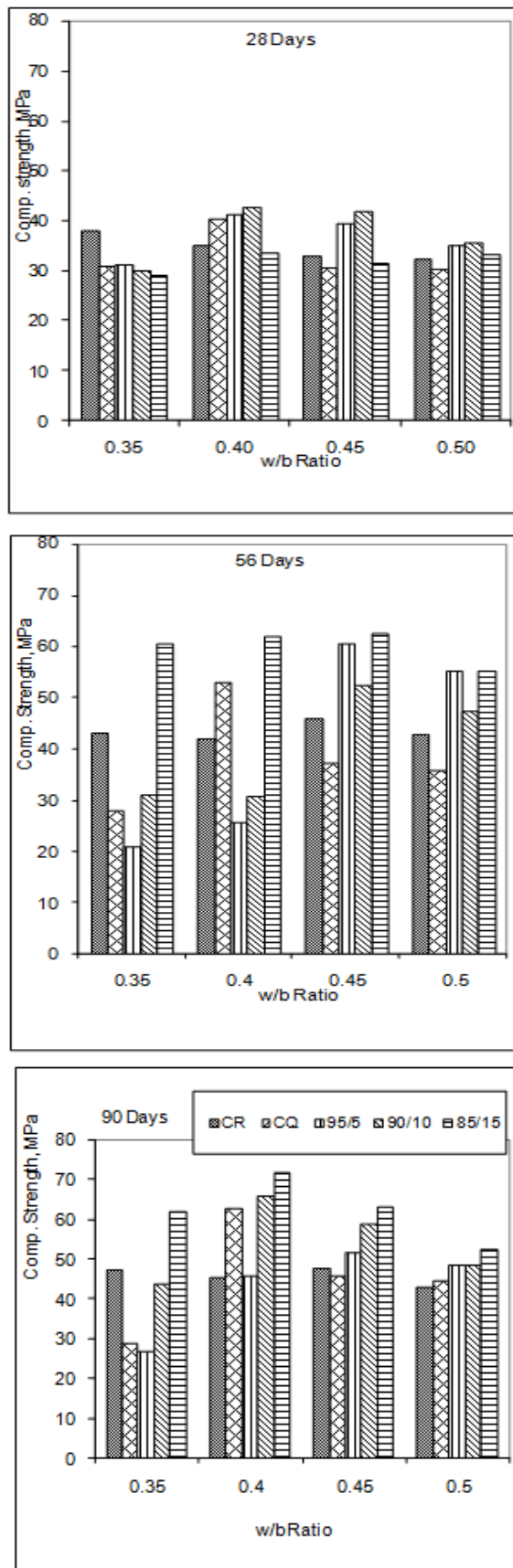


Figure 3. Effect of water binder ratio on compressive strength

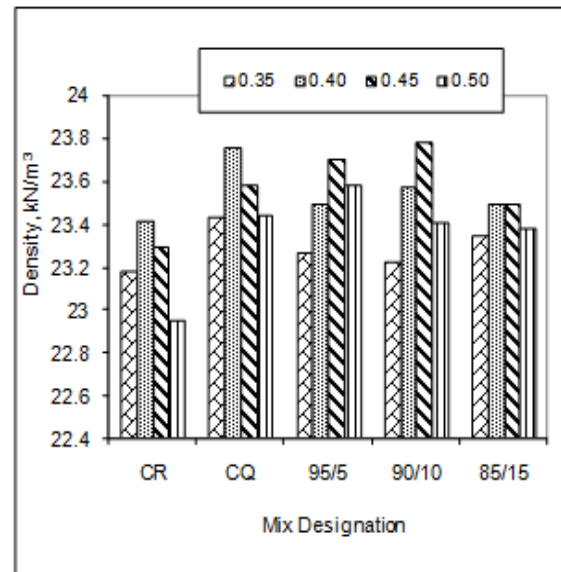


Figure 4. Density of mortar cubes.

REFERENCES

- [1] Ilangoan, R., N. Mahendran, and K. Nagamani, "Strength and durability properties of concrete containing quarry rock dust as fine aggregate", *ARPJ Journal of Engineering and Applied Sciences*, vol. 3, pp 20-26, May 2008.
- [2] Kou, S.C. and C.S. Poon, "Properties of concrete prepared with crushed fine stone, furnace bottom ash and fine recycled aggregate as fine aggregates", *Construction and Building Materials*, vol. 23, pp. 2877-2886, 2009.
- [3] Celik, T. and K. Marar, "Effects of crushed stone dust on some properties of concrete", *Cement and Concrete Research*, vol. 26, pp. 1121-1130, July 1996.
- [4] Wild, S., J.M. Khatib, and A. Jones, "Relative strength, pozzolanic activity and cement hydration in super plasticized metakaolin concrete", *Cement and Concrete Research*, vol. 26, pp. 1537-1544, Oct. 1996.
- [5] Curcio, F., B.A. DeAngelis, and S. Pagliolico, "Metakaolin as a pozzolanic micro filler for high performance mortars", *Cement and Concrete Research*, vol. 28, pp. 803-809, June 1998.
- [6] Poon, C. S., L. Lama, , S.C. Kou, , Y.L. Wong, and R. Wong, "Rate of pozzolanic reaction of metakaolin in high-performance cement paste", *Cement and Concrete Research*, vol. 31 pp. 1301-1306, 2001.
- [7] Aitcin, P. C. "Binders for durable and sustainable concrete, Taylor & Francis, New York, 2008.